Time travel

Time travel is the concept of movement between certain points in time, analogous to movement between different points in space by an object or a person, typically using a hypothetical device known as a **time machine**. Time travel is a widely-recognized concept in philosophy and fiction. The idea of a time machine was popularized by H. G. Wells' 1895 novel *The Time Machine*.

It is uncertain if time travel to the past is physically possible. Forward time travel, outside the usual sense of the perception of time, is an extensively-observed phenomenon and well-understood within the framework of special relativity and general relativity. However, making one body advance or delay more than a few milliseconds compared to another body is not feasible with current technology. As for backwards time travel, it is possible to find solutions in general relativity that allow for it, but the solutions require conditions that may not be physically possible. Traveling to an arbitrary point in spacetime has a very limited support in theoretical physics, and usually only connected with quantum mechanics or wormholes, also known as Einstein-Rosen bridges.

Contents

History of the time travel concept
- Shift to science fiction
- Early time machines

Time travel in physics
- General relativity
  - Different spacetime geometries
  - Wormholes
  - Other approaches based on general relativity
- Quantum physics
  - No-communication theorem
  - Interacting many-worlds interpretation
- Experimental results
- Absence of time travelers from the future

Forward time travel in physics
- Time dilation

Philosophy
- Presentism vs. eternalism
- The grandfather paradox
- Ontological paradox
  - Compossibility
  - Self-consistency principle

In fiction

See also

References

External links

History of the time travel concept

Some ancient myths depict a character skipping forward in time. In Hindu mythology, the *Mahabharata* mentions the story of King Raivata Kakudmi, who travels to heaven to meet the creator Brahma and is surprised to learn when he returns to Earth that many ages have passed.[1] The Buddhist Pāli Canon mentions the relativity of time. The Payasi Sutta tells of one of the Buddha's chief disciples,

Kumara Kassapa, who explains to the skeptic Payasi that time in the Heavens passes differently than on Earth.[2] The Japanese tale of "Urashima Tarō",[3] first described in the *Nihongi* (720) tells of a young fisherman named Urashima Taro who visits an undersea palace. After three days, he returns home to his village and finds himself 300 years in the future, where he has been forgotten, his house is in ruins, and his family has died.[4] In Jewish tradition, the 1st-century BC scholar Honi ha-M'agel is said to have fallen asleep and slept for seventy years. When waking up he returned home but found none of the people he knew, and no one believed his claims of who he was.[5]

Statue of Rip Van Winkle in Irvington, New York

Shift to science fiction

Early science fiction stories feature characters who sleep for years and awaken in a changed society, or are transported to the past through supernatural means. Among them *L'An 2440, rêve s'il en fût jamais* (1770) by Louis-Sébastien Mercier, *Rip Van Winkle* (1819) by Washington Irving, *Looking Backward* (1888) by Edward Bellamy, and *When the Sleeper Awakes* (1899) by H.G. Wells. Prolonged sleep, like the more familiar time machine, is used as a means of time travel in these stories.[6]

The earliest work about backwards time travel is uncertain. Samuel Madden's *Memoirs of the Twentieth Century* (1733) is a series of letters from British ambassadors in 1997 and 1998 to diplomats in the past, conveying the political and religious conditions of the future.[7]:95–96 Because the narrator receives these letters from his guardian angel, Paul Alkon suggests in his book *Origins of Futuristic Fiction* that "the first time-traveler in English literature is a guardian angel."[7]:85 Madden does not explain how the angel obtains these documents, but Alkon asserts that Madden "deserves recognition as the first to toy with the rich idea of time-travel in the form of an artifact sent backward from the future to be discovered in the present."[7]:95–96 In the science fiction anthology *Far Boundaries* (1951), editor August Derleth claims that an early short story about time travel is *Missing One's Coach: An Anachronism*, written for the *Dublin Literary Magazine*[8] by an anonymous author in 1838.[9]:3 While the narrator waits under a tree for a coach to take him out of Newcastle, he is transported back in time over a thousand years. He encounters the Venerable Bede in a monastery and explains to him the developments of the coming centuries. However, the story never makes it clear whether these events are real or a dream.[9]:11–38 Another early work about time travel is *The Forebears of Kalimeros: Alexander, son of Philip of Macedon* by Alexander Veltman published in 1836.[10]

Charles Dickens's *A Christmas Carol* (1843) has early depictions of time travel in both directions, as the protagonist, Ebenezer Scrooge, is transported to Christmases past and future. Other stories employ the same template, where a character naturally goes to sleep, and upon waking up finds themself in a different time.[11] A clearer example of backward time travel is found in the popular 1861 book *Paris avant les hommes* (Paris before Men) by the French botanist and geologist Pierre Boitard, published posthumously. In this story, the protagonist is transported to the prehistoric past by the magic of a "lame demon" (a French pun on Boitard's name), where he encounters a Plesiosaur and an apelike ancestor and is able to interact with ancient creatures.[12] Edward Everett Hale's "Hands Off" (1881) tells the story of an unnamed being, possibly the soul of a person who has recently died, who interferes with ancient Egyptian history by preventing Joseph's enslavement. This may have been the first story to feature an alternate history created as a result of time travel.[13]:54

Mr. and Mrs. Fezziwig dance in a vision shown to Scrooge by the Ghost of Christmas Past

Early time machines

One of the first stories to feature time travel by means of a machine is "The Clock that Went Backward" by Edward Page Mitchell,[14] which appeared in the *New York Sun* in 1881. However, the mechanism borders on fantasy. An unusual clock, when wound, runs backwards and transports people

nearby back in time. The author does not explain the origin or properties of the clock.[13]:55 Enrique Gaspar y Rimbau's *El Anacronópete* (1887) may have been the first story to feature a vessel engineered to travel through time.[15][16] Andrew Sawyer has commented that the story "does seem to be the first literary description of a time machine noted so far", adding that "Edward Page Mitchell's story 'The Clock That Went Backward' (1881) is usually described as the first time-machine story, but I'm not sure that a clock quite counts."[17] H. G. Wells's *The Time Machine* (1895) popularized the concept of time travel by mechanical means.[18]

Time travel in physics

Some theories, most notably special and general relativity, suggest that suitable geometries of spacetime or specific types of motion in space might allow time travel into the past and future if these geometries or motions were possible.[19]:499 In technical papers, physicists discuss the possibility of closed timelike curves, which are world lines that form closed loops in spacetime, allowing objects to return to their own past. There are known to be solutions to the equations of general relativity that describe spacetimes which contain closed timelike curves, such as Gödel spacetime, but the physical plausibility of these solutions is uncertain.

Many in the scientific community believe that backward time travel is highly unlikely. Any theory that would allow time travel would introduce potential problems of causality.[20] The classic example of a problem involving causality is the "grandfather paradox": what if one were to go back in time and kill one's own grandfather before one's father was conceived? Some physicists, such as Novikov and Deutsch, suggested that these sorts of temporal paradoxes can be avoided through the Novikov self-consistency principle or to a variation of the many-worlds interpretation with interacting worlds.[21]

General relativity

Time travel to the past is theoretically possible in certain general relativity spacetime geometries that permit traveling faster than the speed of light, such as cosmic strings, transversable wormholes, and Alcubierre drive.[22][23]:33–130 The theory of general relativity does suggest a scientific basis for the possibility of backward time travel in certain unusual scenarios, although arguments from semiclassical gravity suggest that when quantum effects are incorporated into general relativity, these loopholes may be closed.[24] These semiclassical arguments led Stephen Hawking to formulate the chronology protection conjecture, suggesting that the fundamental laws of nature prevent time travel,[25] but physicists cannot come to a definite judgment on the issue without a theory of quantum gravity to join quantum mechanics and general relativity into a completely unified theory.[26][27]:150

Different spacetime geometries

The theory of general relativity describes the universe under a system of field equations that determine the metric, or distance function, of spacetime. There exist exact solutions to these equations that include closed time-like curves, which are world lines that intersect themselves; some point in the causal future of the world line is also in its causal past, a situation which is akin to time travel. Such a solution was first proposed by Kurt Gödel, a solution known as the Gödel metric, but his (and others') solution requires the universe to have physical characteristics that it does not appear to have,[19]:499 such as rotation and lack of Hubble expansion. Whether general relativity forbids closed time-like curves for all realistic conditions is still being researched.[28]

Wormholes

Wormholes are a hypothetical warped spacetime which are permitted by the Einstein field equations of general relativity.[29]:100 A proposed time-travel machine using a traversable wormhole would hypothetically work in the following way: One end of the wormhole is accelerated to some significant fraction of the speed of light, perhaps with some advanced propulsion system, and then brought back to the point of origin. Alternatively, another way is to take one entrance of the wormhole and move it to within the gravitational field of an object that has higher gravity than the other entrance, and then return it to a position near the other entrance. For both of these methods, time dilation causes the end of the wormhole that has been moved to have aged less, or become "younger", than the stationary end as seen by an external observer; however, time connects differently *through* the wormhole than *outside* it, so that synchronized clocks at either end of the wormhole will always remain synchronized as seen by an observer passing through the wormhole, no matter how the two ends move around.[19]:502 This means that an observer entering the "younger" end would exit the "older" end at a time when it was the same age as the "younger" end, effectively going back in time as seen by an

observer from the outside. One significant limitation of such a time machine is that it is only possible to go as far back in time as the initial creation of the machine;[19]:503 in essence, it is more of a path through time than it is a device that itself moves through time, and it would not allow the technology itself to be moved backward in time.

According to current theories on the nature of wormholes, construction of a traversable wormhole would require the existence of a substance with negative energy, often referred to as "exotic matter". More technically, the wormhole spacetime requires a distribution of energy that violates variousenergy conditions, such as the null energy condition along with the weak, strong, and dominant energy conditions. However, it is known that quantum effects can lead to small measurable violations of the null energy condition,[29]:101 and many physicists believe that the required negative energy may actually be possible due to the Casimir effect in quantum physics.[30] Although early calculations suggested a very large amount of negative energy would be required, later calculations showed that the amount of negative energy can be made arbitrarily small.[31]

In 1993, Matt Visser argued that the two mouths of a wormhole with such an induced clock difference could not be brought together without inducing quantum field and gravitational effects that would either make the wormhole collapse or the two mouths repel each other.[32] Because of this, the two mouths could not be brought close enough for causality violation to take place. However, in a 1997 paper, Visser hypothesized that a complex "Roman ring" (named after Tom Roman) configuration of an N number of wormholes arranged in a symmetric polygon could still act as a time machine, although he concludes that this is more likely a flaw in classical quantum gravity theory rather than proof that causality violation is possible.[33]

Other approaches based on general relativity

Another approach involves a dense spinning cylinder usually referred to as a Tipler cylinder, a GR solution discovered by Willem Jacob van Stockum[34] in 1936 and Kornel Lanczos[35] in 1924, but not recognized as allowing closed timelike curves[36]:21 until an analysis by Frank Tipler[37] in 1974. If a cylinder is infinitely long and spins fast enough about its long axis, then a spaceship flying around the cylinder on a spiral path could travel back in time (or forward, depending on the direction of its spiral). However, the density and speed required is so great that ordinary matter is not strong enough to construct it. A similar device might be built from a cosmic string, but none are known to exist, and it does not seem to be possible to create a new cosmic string. Physicist Ronald Mallett is attempting to recreate the conditions of a rotating black hole with ring lasers, in order to bend spacetime and allow for time travel.[38]

A more fundamental objection to time travel schemes based on rotating cylinders or cosmic strings has been put forward by Stephen Hawking, who proved a theorem showing that according to general relativity it is impossible to build a time machine of a special typ (a "time machine with the compactly generated Cauchy horizon") in a region where the weak energy condition is satisfied, meaning that the region contains no matter with negative energy density (exotic matter). Solutions such as Tipler's assume cylinders of infinite length, which are easier to analyze mathematically, and although Tipler suggested that a finite cylinder might produce closed timelike curves if the rotation rate were fast enough,[36]:169 he did not prove this. But Hawking points out that because of his theorem, "it can't be done with positive energy density everywhere! I can prove that to build a finite time machine, you need negative energy."[27]:96 This result comes from Hawking's 1992 paper on the chronology protection conjecture, where he examines "the case that the causality violations appear in a finite region of spacetime without curvature singularities" and proves that "there will be a Cauchy horizon that is compactly generated and that in general contains one or more closed null geodesics which will be incomplete. One can define geometrical quantities that measure the Lorentz boost and area increase on going round these closed null geodesics. If the causality violation developed from a noncompact initial surface, the averaged weak energy condition must be violated on the Cauchy horizon."[25] This theorem does not rule out the possibility of time travel by means of time machines with the non-compactly generated Cauchy horizons (such as the Deutsch-Politzer time machine) or in regions which contain exotic matter, which would be used for traversable wormholes or theAlcubierre drive.

Quantum physics

No-communication theorem

When a signal is sent from one location and received at another location, then as long as the signal is moving at the speed of light or slower, the mathematics of simultaneity in the theory of relativity show that all reference frames agree that the transmission-event happened before the reception-event. When the signal travels faster than light, it is received *before* it is sent, in all reference frames.[39] The signal could be said to have moved backward in time. This hypothetical scenario is sometimes referred to as a tachyonic antitelephone.[40]

Quantum-mechanical phenomena such as quantum teleportation, the EPR paradox, or quantum entanglement might appear to create a mechanism that allows for faster-than-light (FTL) communication or time travel, and in fact some interpretations of quantum mechanics such as the Bohm interpretation presume that some information is being exchanged between particles instantaneously in order to maintain correlations between particles.[41] This effect was referred to as 'spooky action at a distance' by Einstein.

Nevertheless, the fact that causality is preserved in quantum mechanics is a rigorous result in modern quantum field theories, and therefore modern theories do not allow for time travel or FTL communication. In any specific instance where FTL has been claimed, more detailed analysis has proven that to get a signal, some form of classical communication must also be used.[42] The no-communication theorem also gives a general proof that quantum entanglement cannot be used to transmit information faster than classical signals.

Interacting many-worlds interpretation

A variation of Everett's many-worlds interpretation (MWI) of quantum mechanics provides a resolution to the grandfather paradox that involves the time traveler arriving in a different universe than the one they came from; it's been argued that since the traveler arrives in a different universe's history and not their own history, this is not "genuine" time travel.[43] The accepted many-worlds interpretation suggests that all possible quantum events can occur in mutually exclusive histories.[44] However, some variations allow different universes to interact. This concept is most often used in science-fiction, but some physicists such as David Deutsch have suggested that a time traveler should end up in a different history than the one he started from.[45][46] On the other hand, Stephen Hawking has argued that even if the MWI is correct, we should expect each time traveler to experience a single self-consistent history, so that time travelers remain within their own world rather than traveling to a different one.[47] The physicist Allen Everett argued that Deutsch's approach "involves modifying fundamental principles of quantum mechanics; it certainly goes beyond simply adopting the MWI". Everett also argues that even if Deutsch's approach is correct, it would imply that any macroscopic object composed of multiple particles would be split apart when traveling back in time through a wormhole, with different particles emerging in different worlds.[21]

Experimental results

Certain experiments carried out give the impression of reversed causality, but fail to show it under closer examination.

The delayed choice quantum eraser experiment performed by Marlan Scully involves pairs of entangled photons that are divided into "signal photons" and "idler photons", with the signal photons emerging from one of two locations and their position later measured as in the double-slit experiment. Depending on how the idler photon is measured, the experimenter can either learn which of the two locations the signal photon emerged from or "erase" that information. Even though the signal photons can be measured before the choice has been made about the idler photons, the choice seems to retroactively determine whether or not an interference pattern is observed when one correlates measurements of idler photons to the corresponding signal photons. However, since interference can only be observed after the idler photons are measured and they are correlated with the signal photons, there is no way for experimenters to tell what choice will be made in advance just by looking at the signal photons, only by gathering classical information from the entire system; thus causality is preserved.[48]

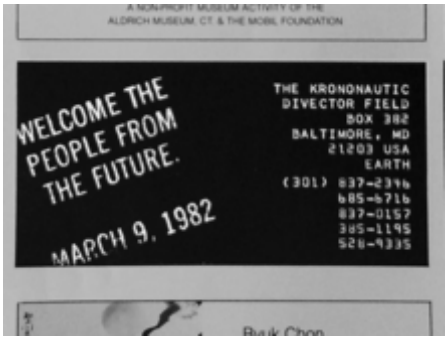
The experiment of Lijun Wang might also show causality violation since it made it possible to send packages of waves through a bulb of caesium gas in such a way that the package appeared to exit the bulb 62 nanoseconds before its entry, but a wave package is not a single well-defined object but rather a sum of multiple waves of different frequencies (see Fourier analysis), and the package can appear to move faster than light or even backward in time even if none of the pure waves in the sum do so. This effect cannot be used to send any matter, energy, or information faster than light,[49] so this experiment is understood not to violate causality either

The physicists Günter Nimtz and Alfons Stahlhofen, of the University of Koblenz, claim to have violated Einstein's theory of relativity by transmitting photons faster than the speed of light. They say they have conducted an experiment in which microwave photons traveled "instantaneously" between a pair of prisms that had been moved up to 3 ft (0.91 m) apart, using a phenomenon known as quantum tunneling. Nimtz told *New Scientist* magazine: "For the time being, this is the only violation of special relativity that I know of." However, other physicists say that this phenomenon does not allow information to be transmitted faster than light. Aephraim Steinberg, a quantum optics expert at the University of Toronto, Canada, uses the analogy of a train traveling from Chicago to New York, but dropping off train cars at each station along the way, so that the center of the train moves forward at each stop; in this way, the speed of the center of the train exceeds the speed of any of the individual cars.[50]

Shengwang Du claims in a peer-reviewed journal to have observed single photons' precursors, saying that they travel no faster than *c* in a vacuum. His experiment involved slow light as well as passing light through a vacuum. He generated two single photons, passing one through rubidium atoms that had been cooled with a laser (thus slowing the light) and passing one through a vacuum. Both times, apparently, the precursors preceded the photons' main bodies, and the precursor traveled at *c* in a vacuum. According to Du, this implies that there is no possibility of light traveling faster than *c* and, thus, no possibility of violating causality.[51]

Absence of time travelers from the future

The absence of time travelers from the future is a variation of the Fermi paradox. As the absence of extraterrestrial visitors does not prove they do not exist, so the absence of time travelers fails to prove time travel is physically impossible; it might be that time travel is physically possible but is never developed or is cautiously used. Carl Sagan once suggested the possibility that time travelers could be here but are disguising their existence or are not recognized as time travelers.[26] Some versions of general relativity suggest that time travel might only be possible in a region of spacetime that is warped a certain way and hence time travelers would not be able to travel back to earlier regions in spacetime, before this region existed. Stephen Hawking stated that this would explain why the world has not already been overrun by "tourists from the future."[47]



Krononauts

Several experiments have been carried out to try to entice future humans, who might invent time travel technology, to come back and demonstrate it to people of the present time. Events such as Perth's Destination Day or MIT's Time Traveler Convention heavily publicized permanent "advertisements" of a meeting time and place for future time travelers to meet.[52] In 1982, a group in Baltimore, Maryland, identifying itself as the Krononauts, hosted an event of this type welcoming visitors from the future.[53][54] These experiments only stood the possibility of generating a positive result demonstrating the existence of time travel, but have failed so far—no time travelers are known to have attended either event. Some versions of the many-worlds interpretation can be used to suggest that future humans have traveled back in time, but have traveled back to the meeting time and place in a parallel universe.[55]

Forward time travel in physics

Time dilation

There is a great deal of observable evidence for time dilation in special relativity[56] and gravitational time dilation in general relativity,[57][58][59] for example in the famous and easy-to-replicate observation of atmospheric muon decay.[60][61][62] The theory of relativity states that the speed of light is invariant for all observers in any frame of reference; that is, it is always the same. Time dilation is a direct consequence of the invariance of the speed of light.[62] Time dilation may be regarded in a limited sense as "time travel into the future": a person may use time dilation so that a small amount of proper time passes for them, while a large amount of proper time passes elsewhere. This can be achieved by traveling at relativistic speeds or through the effects of gravity.[63]

For two identical clocks moving relative to each other without accelerating, each clock measures the other to be ticking slower. This is possible due to the relativity of simultaneity. However, the symmetry is broken if one clock accelerates, allowing for less proper time to pass for one clock than the other. The twin paradox describes this: one twin remains on Earth, while the other undergoes acceleration to relativistic speed as they travel into space, turn around, and travel back to Earth; the traveling twin ages less than the twin who stayed on Earth, because of the time dilation experienced during their acceleration. General relativity treats the effects of acceleration and the effects of gravity as equivalent, and shows that time dilation also occurs in gravity wells, with a clock deeper in the well ticking more slowly; this effect is taken into account when calibrating the clocks on the satellites of the Global Positioning System, and it could lead to significant differences in rates of aging for observers at different distances from a large gravity well such as a black hole.[23]:33–130

Transversal time dilation. The blue dots represent a pulse of light. Each pair of dots with light "bouncing" between them is a clock. For each group of clocks, the other group appears to be ticking more slowly because the moving clock's light pulse has to travel a larger distance than the stationary clock's light pulse. That is so, even though the clocks are identical and their relative motion is perfectly reciprocal.

A time machine that utilizes this principle might be, for instance, a spherical shell with a diameter of 5 meters and the mass of Jupiter. A person at its center will travel forward in time at a rate four times that of distant observers. Squeezing the mass of a large planet into such a small structure is not expected to be within humanity's technological capabilities in the near future.[23]:76–140 With current technologies, it is only possible to cause a human traveler to age less than companions on Earth by a few milliseconds, the current record being about 20 milliseconds for the cosmonaut Sergei Krikalev.[64]

Philosophy

Philosophers have discussed the nature of time since at least the time of ancient Greece; for example, Parmenides presented the view that time is an illusion. Centuries later, Isaac Newton supported the idea of absolute time, while his contemporary Gottfried Wilhelm Leibniz maintained that time is only a relation between events and it cannot be expressed independently The latter approach eventually gave rise to the spacetime of relativity.[65]

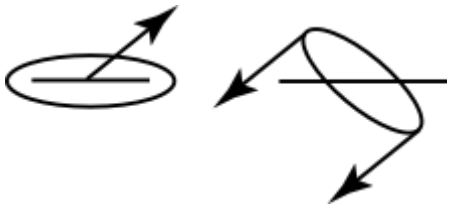
Presentism vs. eternalism

Many philosophers have argued that relativity implies eternalism, the idea that the past and future exist in a real sense, not only as changes that occurred or will occur to the present.[66] Philosopher of science Dean Rickles disagrees with some qualifications, but notes that "the consensus among philosophers seems to be that special and general relativity are incompatible with presentism."[67] Some philosophers view time as a dimension equal to spatial dimensions, that future events are "already there" in the same sense different places exist, and that there is no objective flow of time; however, this view is disputed.[68]

Presentism is a school of philosophy that holds that the future and the past exist only as changes that occurred or will occur to the present, and they have no real existence of their own. In this view, time travel is impossible because there is no future or past to travel to.[66] Keller and Nelson have argued that even if past and future objects do not exist, there can still be definite truths about past and future events, and thus it is possible that a future truth about a time traveler deciding to travel back to the present date could explain the time traveler's actual appearance in the present;[69] these views are contested by some authors.[70]

Presentism in classical spacetime deems that only the present exists; this is not reconcilable with special relativity, shown in the following example: Alice and Bob are simultaneous observers of event *O*. For Alice, some event *E* is simultaneous with *O*, but for Bob, event *E* is in the past or future. Therefore, Alice and Bob disagree about what exists in the present, which contradicts classical presentism. "Here-now presentism" attempts to reconcile this by only acknowledging the time and space of a single point; this is unsatisfactory because objects coming and going from the "here-now" alternate between real and unreal, in addition to the lack of a privileged "here-now" that would be the "real" present. "Relativized presentism" acknowledges that there are infinite frames of

reference, each of them has a different set of simultaneous events, which makes it impossible to distinguish a single "real" present, and hence either all events in time are real—blurring the difference between presentism and eternalism—or each frame of reference exists in its own reality. Options for presentism in special relativity appear to be exhausted, but Gödel and others suspect presentism may be valid for some forms of general relativity.[71] Generally, the idea of absolute time and space is considered incompatible with general relativity; there is no universal truth about the absolute position of events which occur at different times, and thus no way to determine which point in space at one time is at the universal "same position" at another time,[72] and all coordinate systems are on equal footing as given by the principle of diffeomorphism invariance.[73]



The bar and ring paradox is an example of the relativity of simultaneity. Both ends of the bar pass through the ring simultaneously in the rest frame of the ring (left), but the ends of the bar pass one after the other in the rest frame of the bar (right).

The grandfather paradox

A common objection to the idea of traveling back in time is put forth in the grandfather paradox or the argument of auto-infanticide.[74] If one were able to go back in time, inconsistencies and contradictions would ensue if the time traveler were to change anything; there is a contradiction if the past becomes different from the way it *is*.[75][76] The paradox is commonly described with a person who travels to the past and kills their own grandfather, prevents the existence of their father or mother, and therefore their own existence.[26] Philosophers question whether these paradoxes make time travel impossible. Some philosophers answer the paradoxes by arguing that it might be the case that backward time travel could be possible but that it would be impossible to actually *change* the past in any way,[77] an idea similar to the proposed Novikov self-consistency principle in physics.

Ontological paradox

Compossibility

According to the philosophical theory of compossibility, what *can* happen, for example in the context of time travel, must be weighed against the context of everything relating to the situation. If the past *is* a certain way, it's not possible for it to be any other way. What *can* happen when a time traveler visits the past is limited to what *did* happen, in order to prevent logical contradictions.[78]

Self-consistency principle

The Novikov self-consistency principle, named after Igor Dmitrievich Novikov, states that any actions taken by a time traveler or by an object that travels back in time were part of history all along, and therefore it is impossible for the time traveler to "change" history in any way. The time traveler's actions may be the *cause* of events in their own past though, which leads to the potential for circular causation, sometimes called a predestination paradox,[79] ontological paradox,[80] or bootstrap paradox.[80][81] The term bootstrap paradox was popularized by Robert A. Heinlein's story "By His Bootstraps".[82] The Novikov self-consistency principle proposes that the local laws of physics in a region of spacetime containing time travelers cannot be any different from the local laws of physics in any other region of spacetime.[83]

The philosopher Kelley L. Ross argues in "Time Travel Paradoxes"[84] that in a scenario involving a physical object whose world-line or history forms a closed loop in time there can be a violation of the second law of thermodynamics. Ross uses "Somewhere in Time" as an example of such an ontological paradox, where a watch is given to a person, and 60 years later the same watch is brought back in time and given to the same character. Ross states that entropy of the watch will increase, and the watch carried back in time will be more worn with each repetition of its history. The second law of thermodynamics is understood by modern physicists to be a statistical law, so decreasing entropy or non-increasing entropy are not impossible, just improbable. Additionally, entropy statistically increases in systems which are isolated, so non-isolated systems, such as an object, that interact with the outside world, can become less worn and decrease in entropy, and it's possible for an object whose world-line forms a closed loop to be always in the same condition in the same point of its history.[23]:23

Daniel Greenberger and Karl Svozil proposed that quantum theory gives a model for time travel where the past must be self-consistent.[85][86]

In fiction

Time travel themes in science fiction and the media can generally be grouped into three categories: immutable timeline; mutable timeline; and alternate histories, as in the interacting-many-worlds interpretation.[87][88][89] Frequently in fiction, *timeline* is used to refer to all physical events in history, so that in time travel stories where events can be changed, the time traveler is described as creating a new or altered timeline.[90] This usage is distinct from the use of the term timeline to refer to a type of chart that illustrates a particular series of events, and the concept is also distinct from a world line, a term from Einstein's theory of relativity which refers to the entire history of a *single* object.

See also

Claims of time travel

- Time travel claims and urban legends

Culture

- Time capsule

Fiction

- Time travel in fiction
- List of time travel works of fiction
- List of games containing time travel
- List of television series that include time travel

Science

- Krasnikov tube
- Retrocausality
- Ring singularity
- Temporal paradox
- Wheeler–Feynman absorber theory

Time perception

- Cryonics
- Suspended animation
- Time perception

References

1. Dowson, John (1879), "Revati" (http://www.mythfolklore.net/india/encyclopedia/revati.htm), *A classical dictionary of Hindu mythology and religion, geography, history, and literature*, Routledge
2. Debiprasad Chattopadhyaya (1964), *Indian Philosophy* (7 ed.), People's Publishing House, New Delhi
3. Yorke, Christopher (February 2006). "Malchronia: Cryonics and Bionics as Primitive Weapons in the War on Time" (http://jetpress.org/volume15/yorke-rowe.html) *Journal of Evolution and Technology*. **15** (1): 73–85. Retrieved August 29, 2009.
4. Rosenberg, Donna (1997). *Folklore, myths, and legends: a world perspective* McGraw-Hill. p. 421. ISBN 978-0-8442-5780-8.

5. Taanit 23a Hebrew/Aramaic text at Mechon-Mamre (http://www.mechon-mamre.org/b/l/l2803.htm)
6. Peter Fitting (2010), "Utopia, dystopia, and science fiction", in Gregory Claeys (ed.), *The Cambridge Companion to Utopian Literature*, Cambridge University Press, pp. 138–139
7. Alkon, Paul K. (1987). *Origins of Futuristic Fiction* The University of Georgia Press. ISBN 978-0-8203-0932-3
8. "Missing One's Coach: An Anachronism" (https://books.google.com/books?id=jfPAwAnj9JUC&pg=RA1-PA701). *Dublin University Magazine* **11**. March 1838.
9. Derleth, August (1951). *Far Boundaries*. Pellegrini & Cudahy.
10. Akutin, Yury (1978) Александр Вельтман и его роман "Странник" (http://az.lib.ru/w/welxtman_a_f/text_0090.shtml) (Alexander Veltman and his novel *Strannik*, in Russian).
11. Flynn, John L. (1995). "Time Travel Literature" (https://web.archive.org/web/20060929071327/http://www.towson.edu/~flynn/timetv.html). *The Encyclopedia Galactica* Archived from the original (http://www.towson.edu/~flynn/timetv.html) on September 29, 2006. Retrieved October 28, 2006.
12. Rudwick, Martin J. S. (1992). *Scenes From Deep Time*. The University of Chicago Press. pp. 166–169. ISBN 978-0-226-73105-6.
13. Nahin, Paul J. (2001). *Time machines: time travel in physics, metaphysics, and science fiction* (https://books.google.com/books?id=39KQY1FnSfkC&lpg=PP1&pg=PA54). Springer. ISBN 978-0-387-98571-8.
14. Page Mitchell, Edward. "The Clock That Went Backward" (https://web.archive.org/web/20111015110200/http://horrormasters.com/Text/a2221.pdf) (PDF). Archived from the original (http://www.horrormasters.com/Text/a2221.pdf) (PDF) on October 15, 2011. Retrieved December 4, 2011.
15. Uribe, Augusto (June 1999). "The First Time Machine: Enrique Gaspar's Anacronópete". *The New York Review of Science Fiction*. 11, no. 10 (130): 12.
16. Noted in the Introduction (https://books.google.com/books?id=yAUiSP_Mr6wC&lpg=PP1&pg=PT17) to an English translation of the book, *The Time Ship: A Chrononautical Journey* translated by Yolanda Molina-Gavilán and Andrea L. Bell.
17. Westcott, Kathryn. "HG Wells or Enrique Gaspar: Whose time machine was first?" (https://web.archive.org/web/20140329161914/http://www.bbc.co.uk/news/world-europe-12900390). Archived from the original (https://www.bbc.co.uk/news/world-europe-12900390) on March 29, 2014. Retrieved August 1, 2014.
18. Sterling, Bruce (August 27, 2014). "science fiction | literature and performance :: Major science fiction themes" (http://www.britannica.com/art/science-fiction/Major-science-fiction-themes#toc235731). Britannica.com. Retrieved November 27, 2015.
19. Thorne, Kip S. (1994). *Black Holes and Time Warps*. W. W. Norton. ISBN 978-0-393-31276-8
20. Bolonkin, Alexander (2011). *Universe, Human Immortality and Future Human Evaluation* (https://books.google.com/books?id=IFZWTf93KwgC). Elsevier. p. 32. ISBN 978-0-12-415810-8. Extract of page 32 (https://books.google.com/books?id=IFZWTf93KwgC&pg=PA32)
21. Everett, Allen (2004). "Time travel paradoxes, path integrals, and the many worlds interpretation of quantum mechanics". *Physical Review D*. **69** (124023): 124023. arXiv:gr-qc/0410035 (https://arxiv.org/abs/gr-qc/0410035). Bibcode:2004PhRvD..69l4023E (http://adsabs.harvard.edu/abs/2004PhRvD..69l4023E). doi:10.1103/PhysRevD.69.124023 (https://doi.org/10.1103%2FPhysRevD.69.124023)
22. Miguel Alcubierre (June 29, 2012). "Warp Drives, Wormholes, and Black Holes" (http://ccrg.rit.edu/files/FasterThanLight.pdf) (PDF). Retrieved January 25, 2017.
23. J. Richard Gott (25 August 2015). *Time Travel in Einstein's Universe: The Physical Possibilities of Travel Through Time* (https://books.google.com/books?id=3QBgCgAAQBAJ&pg=PT45&lpg=PT45#v=onepage&q&f=false). HMH. p. 33. ISBN 978-0-547-52657-7.
24. Visser, Matt (2002). *The quantum physics of chronology protection*. arXiv:gr-qc/0204022 (https://arxiv.org/abs/gr-qc/0204022). Bibcode:2003ftpc.book..161V (http://adsabs.harvard.edu/abs/2003ftpc.book..161V)
25. Hawking, Stephen (1992). "Chronology protection conjecture" (https://web.archive.org/web/20150227141021/http://thelifeofpsi.com/wp-content/uploads/2014/09/Hawking-1992.pdf) (PDF). *Physical Review D*. **46** (2): 603–611. Bibcode:1992PhRvD..46..603H (http://adsabs.harvard.edu/abs/1992PhRvD..46..603H). doi:10.1103/PhysRevD.46.603 (https://doi.org/10.1103%2FPhysRevD.46.603). Archived from the original (http://thelifeofpsi.com/wp-content/uploads/2014/09/Hawking-1992.pdf) (PDF) on 2015-02-27.
26. "Carl Sagan Ponders Time Travel" (https://www.pbs.org/wgbh/nova/time/sagan.html). *NOVA*. PBS. December 10, 1999. Retrieved April 26, 2017.

27. Hawking, Stephen; Thorne, Kip; Novikov, Igor; Ferris, Timothy; Lightman, Alan (2002). *The Future of Spacetime* (https://books.google.com/books?id=LlVcB7rz4mkC&pg=PA750). W. W. Norton. ISBN 978-0-393-02022-9
28. S. W. Hawking, *Introductory note to 1949 and 1952* in Kurt Gödel, *Collected works*, Volume II (S. Feferman et al., eds).
29. Visser, Matt (1996). *Lorentzian Wormholes* Springer-Verlag. ISBN 978-1-56396-653-8
30. Cramer, John G. (1994). "NASA Goes FTL Part 1: Wormhole Physics" (https://web.archive.org/web/20060627211046/http://www.npl.washington.edu/av/altvw69.html). *Analog Science Fiction & Fact Magazine* Archived from the original (http://www.npl.washington.edu/av/altvw69.html) on June 27, 2006. Retrieved December 2, 2006.
31. Visser, Matt; Sayan Kar; Naresh Dadhich (2003). "Traversable wormholes with arbitrarily small energy condition violations". *Physical Review Letters* **90** (20): 201102.1–201102.4. arXiv:gr-qc/0301003 (https://arxiv.org/abs/gr-qc/0301003). Bibcode:2003PhRvL..90t1102V (http://adsabs.harvard.edu/abs/2003PhRvL..90t1102V). doi:10.1103/PhysRevLett.90.201102 (https://doi.org/10.1103%2FPhysRevLett.90.201102). PMID 12785880 (https://www.ncbi.nlm.nih.gov/pubmed/12785880)
32. Visser, Matt (1993). "From wormhole to time machine: Comments on Hawking's Chronology Protection Conjecture". *Physical Review D*. **47** (2): 554–565. arXiv:hep-th/9202090 (https://arxiv.org/abs/hep-th/9202090). Bibcode:1993PhRvD..47..554V (http://adsabs.harvard.edu/abs/1993PhRvD..47..554V). doi:10.1103/PhysRevD.47.554 (https://doi.org/10.1103%2FPhysRevD.47.554)
33. Visser, Matt (1997). "Traversable wormholes: the Roman ring". *Physical Review D*. **55** (8): 5212–5214. arXiv:gr-qc/9702043 (https://arxiv.org/abs/gr-qc/9702043). Bibcode:1997PhRvD..55.5212V (http://adsabs.harvard.edu/abs/1997PhRvD..55.5212V). doi:10.1103/PhysRevD.55.5212 (https://doi.org/10.1103%2FPhysRevD.55.5212)
34. van Stockum, Willem Jacob (1936). "The Gravitational Field of a Distribution of Particles Rotating about an Axis of Symmetry" (https://web.archive.org/web/20080819215608/http://www-lorentz.leidenuniv.nl/history/stockum/Proc_R_Soc_Edinb_57_135_1937.jpg). *Proceedings of the Royal Society of Edinburgh*. Archived from the original (http://www-lorentz.leidenuniv.nl/history/stockum/Proc_R_Soc_Edinb_57_135_1937.jpg) on 2008-08-19.
35. Lanczos, Kornel (1924). "On a Stationary Cosmology in the Sense of Einstein's Theory of Gravitation". *General Relativity and Gravitation* Springland Netherlands. **29** (3): 363–399. doi:10.1023/A:1010277120072 (https://doi.org/10.1023%2FA%3A1010277120072)
36. Earman, John (1995). *Bangs, Crunches, Whimpers, and Shrieks: Singularities and Acausalities in Relativistic Spacetimes*. Oxford University Press. Bibcode:1995bcws.book.....E (http://adsabs.harvard.edu/abs/1995bcws.book.....E). ISBN 978-0-19-509591-3
37. Tipler, Frank J (1974). "Rotating Cylinders and the Possibility of Global Causality Violation". *Physical Review D*. **9** (8): 2203. Bibcode:1974PhRvD...9.2203T (http://adsabs.harvard.edu/abs/1974PhRvD...9.2203T). doi:10.1103/PhysRevD.9.2203 (https://doi.org/10.1103%2FPhysRevD.9.2203)
38. Erik Ofgang (August 13, 2015), "UConn Professor Seeks Funding for Time Machine Feasibility Study" (http://www.connecticutmag.com/health-and-science/uconn-professor-seeks-funding-for-time-machine-feasibility-study/article_6f20c86e-7bf1-5796-a214-eb1bea3ed98f.html), *Connecticut Magazine*, retrieved May 8, 2017
39. Jarrell, Mark. "The Special Theory of Relativity" (https://web.archive.org/web/20060913173236/http://www.physics.uc.edu/~jarrell/COURSES/ELECTRODYNAMICS/Chap11/chap11.pdf) (PDF). pp. 7–11. Archived from the original (http://www.physics.uc.edu/~jarrell/COURSES/ELECTRODYNAMICS/Chap11/chap11.pdf) (PDF) on September 13, 2006. Retrieved October 27, 2006.
40. Kowalczyński, Jerzy (January 1984). "Critical comments on the discussion about tachyonic causal paradoxes and on the concept of superluminal reference frame" *International Journal of Theoretical Physics* Springer Science+Business Media **23** (1): 27–60. Bibcode:1984IJTP...23...27K (http://adsabs.harvard.edu/abs/1984IJTP..23...27K). doi:10.1007/BF02080670 (https://doi.org/10.1007%2FBF02080670)
41. Goldstein, Sheldon (March 27, 2017). "Bohmian Mechanics" (http://plato.stanford.edu/entries/qm-bohm/). Retrieved April 26, 2017.
42. Nielsen, Michael; Chuang, Isaac (2000). *Quantum Computation and Quantum Information* Cambridge. p. 28. ISBN 978-0-521-63235-5
43. Frank Arntzenius; Tim Maudlin (December 23, 2009), "Time Travel and Modern Physics" (http://plato.stanford.edu/entries/time-travel-phys/), *Stanford Encyclopedia of Philosophy*
44. Vaidman, Lev (January 17, 2014). "Many-Worlds Interpretation of Quantum Mechanics" (http://plato.stanford.edu/entries/qm-manyworlds/). Retrieved April 26, 2017.

45. Deutsch, David (1991). "Quantum mechanics near closed timelike lines" *Physical Review D*. **44** (10): 3197–3217. Bibcode:1991PhRvD..44.3197D (http://adsabs.harvard.edu/abs/1991PhRvD..44.3197D) doi:10.1103/PhysRevD.44.3197 (https://doi.org/10.1103%2FPhysRevD.44.3197)
46. Pieter Kok (February 3, 2013), *Time Travel Explained: Quantum Mechanics to the Rescue?* (https://www.youtube.com/watch?v=uz9eLjO2BrA)
47. Hawking, Stephen (1999). "Space and Time Warps" (http://www.hawking.org.uk/space-and-time-warps.html). Retrieved February 25, 2012.
48. Greene, Brian (2004). *The Fabric of the Cosmos* Alfred A. Knopf. pp. 197–199. ISBN 978-0-375-41288-2
49. Wright, Laura (November 6, 2003). "Score Another Win for Albert Einstein" (http://discovermagazine.com/2003/nov/score-another-win-for-einstein1106) *Discover*.
50. Anderson, Mark (August 18–24, 2007). "Light seems to defy its own speed limit" (https://www.eurekalert.org/pub_releases/2007-08/ns-lst081607.php) *New Scientist*. **195** (2617). p. 10.
51. *HKUST Professors Prove Single Photons Do Not Exceed the Speed of Light* (http://www.ust.hk/eng/news/press_20110719-893.html), The Hong Kong University of Science & Technology, July 17, 2011, retrieved September 5, 2011
52. Mark Baard (September 5, 2005), *Time Travelers Welcome at MIT* (https://www.wired.com/2005/05/time-travelers-welcome-at-mit/), *Wired*, retrieved June 18, 2018
53. Franklin, Ben A. (March 11, 1982). "The night the planets were aligned with Baltimore lunacy" (https://web.archive.org/web/20081206170526/http://select.nytimes.com/gst/abstract.html?res=F70E13FD395F0C728DDDAA0894DA484D81). *The New York Times*. Archived from the original (https://select.nytimes.com/gst/abstract.html?res=F70E13FD395F0C728DDDAA0894DA484D81) on 2008-12-06.
54. "Welcome the People from the Future. March 9, 1982". Ad in *Artforum* p. 90.
55. Jaume Garriga; Alexander Vilenkin (2001). "Many worlds in one". *Phys. Rev. D*. **64** (4): 043511. arXiv:gr-qc/0102010 (https://arxiv.org/abs/gr-qc/0102010) Bibcode:2001PhRvD..64d3511G (http://adsabs.harvard.edu/abs/2001PhRvD..64d3511G). doi:10.1103/PhysRevD.64.043511 (https://doi.org/10.1103%2FPhysRevD.64.043511)
56. Roberts, Tom (October 2007). "What is the experimental basis of Special Relativity?" (http://math.ucr.edu/home/baez/physics/Relativity/SR/experiments.html#Tests_of_time_dilation) Retrieved April 26, 2017.
57. Nave, Carl Rod (2012). "Scout Rocket Experiment" (http://hyperphysics.phy-astr.gsu.edu/hbase/relativ/gratim.html#c3). *HyperPhysics*. Retrieved April 26, 2017.
58. Nave, Carl Rod (2012). "Hafele-Keating Experiment" (http://hyperphysics.phy-astr.gsu.edu/hbase/relativ/airtim.html#c3). *HyperPhysics*. Retrieved April 26, 2017.
59. Pogge, Richard W. (April 26, 2017). "GPS and Relativity" (http://www.astronomy.ohio-state.edu/~pogge/Ast162/Unit5/gps.html). Retrieved April 26, 2017.
60. Easwar, Nalini; Macintire, Douglas A. (1991). "Study of the effect of relativistic time dilation on cosmic ray muon flux – An undergraduate modern physics experiment" *American Journal of Physics* **59** (7): 589–592. Bibcode:1991AmJPh..59..589E (http://adsabs.harvard.edu/abs/1991AmJPh..59..589E) doi:10.1119/1.16841 (https://doi.org/10.1119%2F1.16841)
61. Coan, Thomas; Liu, Tiankuan; Ye, Jingbo (2006). "A Compact Apparatus for Muon Lifetime Measurement and Time Dilation Demonstration in the Undergraduate Laboratory" *American Journal of Physics* **74** (2): 161–164. arXiv:physics/0502103 (https://arxiv.org/abs/physics/0502103) Bibcode:2006AmJPh..74..161C (http://adsabs.harvard.edu/abs/2006AmJPh..74..161C) doi:10.1119/1.2135319 (https://doi.org/10.1119%2F1.2135319)
62. Ferraro, Rafael (2007), "Einstein's Space-Time: An Introduction to Special and General Relativity" *Einstein's Space-Time: An Introduction to Special and General Relativity* Springer Science & Business Media: 52–53, Bibcode:2007esti.book.....F (http://adsabs.harvard.edu/abs/2007esti.book.....F) ISBN 9780387699462
63. Serway, Raymond A. (2000) *Physics for Scientists and Engineers with Modern Physics*, Fifth Edition, Brooks/Cole, p. 1258, ISBN 0030226570.
64. Mowbray, Scott (19 February 2002). "Let's Do the Time Warp Again" (http://www.popsci.com/scitech/article/200202/lets-do-time-warp-again?page=2) Popular Science. Retrieved 8 July 2011. "Spending just over two years in Mir's Earth orbit, going 17,500 miles per hour, put Sergei Avdeyev 1/50th of a second into the future...'he's the greatest time traveler we have so far'"
65. Dagobert D. Runes, ed. (1942), "Time", *The Dictionary of Philosophy*, Philosophical Library, p. 318
66. Thomas M. Crisp (2007), "Presentism, Eternalism, and Relativity Physics" (https://thomasmcrisp.files.wordpress.com/2017/07/presentism-eternalism-and-relativity-physics.pdf) (PDF), in William Lane Craig; Quentin Smith (eds.), *Einstein, Relativity and Absolute Simultaneity* p. footnote 1

67. Dean Rickles (2007), *Symmetry, Structure, and Spacetime* (https://books.google.com/books?id=gDwJYtfoCh8C&lpg=PP1&pg=PA158#v=onepage&q&f=false) p. 158, ISBN 9780444531162, retrieved July 9, 2016
68. Tim Maudlin (2010), "On the Passing of Time" (https://philocosmology.rutgers.edu/images/uploads/TimDavidClass/05-maudlin-chap04.pdf) (PDF), *The Metaphysics Within Physics*, ISBN 9780199575374
69. Keller, Simon; Michael Nelson (September 2001). "Presentists should believe in time-travel" (https://web.archive.org/web/20081028211537/http://people.bu.edu/stk/Papers/Timetravel.pdf) (PDF). *Australian Journal of Philosophy*. **79** (3): 333–345. doi:10.1080/713931204 (https://doi.org/10.1080%2F713931204) Archived from the original (http://people.bu.edu/stk/Papers/Timetravel.pdf) (PDF) on October 28, 2008.
70. Craig Bourne (7 December 2006). *A Future for Presentism* (https://books.google.com/books?id=DJMSDAAAQBAJ) Clarendon Press. ISBN 978-0-19-921280-4
71. Savitt, Steven F. (September 2000), "There's No Time Like the Present (in Minkowski Spacetime)", *Philosophy of Science*, **67** (S1): S563–S574, CiteSeerX 10.1.1.14.6140 (https://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.14.6140), doi:10.1086/392846 (https://doi.org/10.1086%2F392846)
72. Geroch, Robert (1978). *General Relativity From A to B* The University of Chicago Press. p. 124. ISBN 978-0-226-28863-5.
73. Lee Smolin (September 12, 2005). "Einstein Online: Actors on a changing stage" (http://www.einstein-online.info/en/spotlights/background_independence/index.html) *Einstein Online Vol. 01*. Retrieved April 26, 2017.
74. Horwich, Paul (1987). *Asymmetries in Time: Problems in the Philosophy of Science* (2nd ed.). Cambridge, Massachusetts: MIT Press. p. 116. ISBN 978-0262580885
75. Nicholas J.J. Smith (2013). "Time Travel" (http://plato.stanford.edu/entries/time-travel/index.html#CauLoo) *Stanford Encyclopedia of Philosophy*. Retrieved November 2, 2015.
76. Francisco Lobo (2003). "Time, Closed Timelike Curves and Causality". *The Nature of Time: Geometry*. **95**: 289–296. arXiv:gr-qc/0206078v2 (https://arxiv.org/abs/gr-qc/0206078v2) Bibcode:2003ntgp.conf..289L (http://adsabs.harvard.edu/abs/2003ntgp.conf..289L)
77. Norman Swartz (1993). "Time Travel: Visiting the Past" (https://www.sfu.ca/~swartz/time_travel1.htm). Retrieved February 20, 2016.
78. Lewis, David (1976). "The paradoxes of time travel" (http://www.csus.edu/indiv/m/merlinos/Paradoxes%20of%20Time%20Travel.pdf) (PDF). *American Philosophical Quarterly*. **13**: 145–52. arXiv:gr-qc/9603042 (https://arxiv.org/abs/gr-qc/9603042). Bibcode:1996gr.qc.....3042K (http://adsabs.harvard.edu/abs/1996gr.qc.....3042K).
79. Erdmann, Terry J.; Hutzel, Gary (2001). *Star Trek: The Magic of Tribbles*. Pocket Books. p. 31. ISBN 978-0-7434-4623-5.
80. Smeenk, Chris; Wüthrich, Christian (2011), "Time Travel and Time Machines", in Callender, Craig (ed.), *The Oxford Handbook of Philosophy of Time*, Oxford University Press, p. 581, ISBN 978-0-19-929820-4
81. Krasnikov, S. (2001), "The time travel paradox", *Phys. Rev. D*, **65** (6): 06401, arXiv:gr-qc/0109029 (https://arxiv.org/abs/gr-qc/0109029), Bibcode:2002PhRvD..65f4013K (http://adsabs.harvard.edu/abs/2002PhRvD..65f4013K) doi:10.1103/PhysRevD.65.064013 (https://doi.org/10.1103%2FPhysRevD.65.064013)
82. Klosterman, Chuck (2009). *Eating the Dinosaur* (1st Scribner hardcover ed.). New York: Scribner. pp. 60–62 (https://books.google.com/books?id=lZurDFJtAWwC&lpg=PA60&pg=PA60). ISBN 9781439168486.
83. Friedman, John; Michael Morris; Igor Novikov; Fernando Echeverria; Gunnar Klinkhammer; Kip Thorne; Ulvi Yurtsever (1990). "Cauchy problem in spacetimes with closed timelike curves" (http://authors.library.caltech.edu/3737/). *Physical Review D*. **42** (6): 1915. Bibcode:1990PhRvD..42.1915F (http://adsabs.harvard.edu/abs/1990PhRvD..42.1915F). doi:10.1103/PhysRevD.42.1915 (https://doi.org/10.1103%2FPhysRevD.42.1915)
84. Ross, Kelley L. (2016), *Time Travel Paradoxes* (http://www.friesian.com/paradox.htm) retrieved April 26, 2017
85. Greenberger, Daniel M.; Svozil, Karl (2005). "Quantum Theory Looks at Time Travel". *Quo Vadis Quantum Mechanics?*. The Frontiers Collection. p. 63. arXiv:quant-ph/0506027 (https://arxiv.org/abs/quant-ph/0506027) Bibcode:2005qvqm.book...63G (http://adsabs.harvard.edu/abs/2005qvqm.book...63G) doi:10.1007/3-540-26669-0_4 (https://doi.org/10.1007%2F3-540-26669-0_4) ISBN 978-3-540-22188-3
86. Kettlewell, Julianna (June 17, 2005). "New model 'permits time travel'" (http://news.bbc.co.uk/2/hi/4097258.stm) BBC News. Retrieved April 26, 2017.
87. Grey, William (1999). "Troubles with Time Travel". *Philosophy*. Cambridge University Press. **74** (1): 55–70. doi:10.1017/S0031819199001047 (https://doi.org/10.1017%2FS0031819199001047)
88. Rickman, Gregg (2004). *The Science Fiction Film Reader*. Limelight Editions. ISBN 978-0-87910-994-3

89. Schneider, Susan (2009). *Science Fiction and Philosophy: From Time Travel to Superintelligence* Wiley-Blackwell. ISBN 978-1-4051-4907-5
90. Prucher, Jeff (2007) *Brave New Words: The Oxford Dictionary of Science Fiction* p. 230 (https://books.google.com/books?id=iYzi8m8FbEsC&lpg=PP1&pg=PA230).

External links

- Black holes, Wormholes and Time Travel, a Royal Society Lecture
- How Time Travel Will Work at HowStuffWorks
- Time Travel and Modern Physics at the Stanford Encyclopedia of Philosophy
- Time Travel at the Internet Encyclopedia of Philosophy

Retrieved from 'https://en.wikipedia.org/w/index.php?title=Time_travel&oldid=895275020'

This page was last edited on 3 May 2019, at 04:08 (UTC).

Text is available under the Creative Commons Attribution-ShareAlike License; additional terms may apply. By using this site, you agree to the Terms of Use and Privacy Policy. Wikipedia® is a registered trademark of the Wikimedia Foundation, Inc., a non-profit organization.